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COVER SHEET FOR TECHNICAL MEMORANDUMTITLE- Mission Aspects of Lunar Flying
Unit Design and Operation

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FILING CASE NO(S)- 340

AUTHOR(S)-M. H. Kaplan

FILING SUBJECT(S)- Lunar Flying Unit
(ASSIGNED BY AUTHOR(S)- Lunar Surface Mission Planning**ABSTRACT**

Although much work has been done on the development and application of Lunar Flying Units, many man-machine-mission relationships have been essentially ignored. This memorandum analyzes some of the more important interface problems and their effects on LFU operation.

Specific attention is given to lunar lighting and visibility, trajectory profile, line-of-sight requirements, and lunar surface interaction hazards. These are then applied to a sample exploration mission to Hyginus Rille and Crater, emphasizing the importance of the site peculiarities on LFU operation and mission planning.

	
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FROM: M. H. Kaplan

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TECHNICAL MEMORANDUM

1.0 INTRODUCTION

A great deal of technical work has been performed on the development and application of Lunar Flying Units. To date, studies and experiments have shown that these devices will fly, that exploration distances are extended over those of walking missions, and that these devices are fast. Optimization of trajectories with respect to fuel consumption and attitude control techniques have been studied and are still being studied. However, many man-machine-mission relationships have been essentially ignored. Certainly fuel consumption can be minimized by a straightforward process if flight end points and gravity are the only requirements to satisfy. It is another matter to minimize fuel when requirements of end points, gravity, astronaut capabilities, vehicle complexity, and lighting conditions must all be satisfied. Unfortunately, this is the realistic situation which must be considered for decision making purposes. Although optimization of an overall mission usually does not lend itself to a closed-form analysis, some related observations can be made and methods for developing a better mission can be outlined.

The primary objective of this memorandum is to present and discuss some important interface problems and their effects on LFU operation. The approach employed here is to present each problem area separately and in a quantitative manner, when possible. These are then included in a detailed investigation of a sample exploration mission to Hyginus Rille and Crater. Methods of solving these problems are offered in some cases. Specific subjects considered are lunar lighting and visibility, trajectory profile, line-of-sight requirements, and lunar surface interaction hazards. Finally, recommendations are made concerning simulation programs and future study areas.

The LFU is assumed to have the following properties:

Empty weight	=	180 lbs
Astronaut with PLSS	=	370 lbs
Loadable propellant	=	300 lbs
Payload capability	=	370 lbs

It is further assumed that no complex navigational or control equipment is used. Limiting factors on the number of sorties include mission objectives and EVA constraints.

2.0 MISSION RELATED PROBLEM AREAS

2.1 Lighting and Visibility

Lighting and visibility conditions have previously been considered in relation to LM landing maneuvers.^{1,2} However, the existence of such problems during exploration sorties was not investigated. An astronaut moving about the lunar surface is subject to washout and glare situations, as well as variations in contrast. Ignoring such difficulties may be costly in terms of propellant and time. Hazards in excess of those already present may be avoided by understanding and anticipating such situations. Of primary importance is an investigation of the LFU pilot visibility limitations. It would be quite desirable to eliminate situations in which LFU touchdown points and navigational landmarks are in washout or high glare areas. Furthermore, to make identification practical, sufficient contrast is required. Although these conditions can be improved by a dog-leg maneuver in the case of LM touchdown, this is not generally possible or desirable in an LFU sortie because of the peculiarities of selected exploration sites.

Determination of washout and glare situations can be formulated in a general manner by using vector notation. Figure 1 illustrates the nomenclature used for position vectors and angles. Since LFU traverses are small compared to the lunar radius, gravity variations and curvature effects are ignored.

Lines of solar rays are considered parallel under these conditions. LM and LFU landing zones are assumed to be level. For preplanned sorties all values of \vec{R} and \vec{R}_1 are known for known trajectory profiles. Also, the sun location will be known. \vec{R}_1 is the position vector of the i th LFU sortie touchdown point, T_1 . The condition which causes an LFU pilot to experience washout at the LM site when returning from a sortie is $\alpha \leq \epsilon_w$, where ϵ_w is a small angle in which washout is effective.

Since $\cos \alpha = 1 - (\alpha^2/2!) + \dots$, this condition is also

$$-\frac{\vec{R} \cdot \vec{s}}{|\vec{R}|} \geq 1 - \frac{\epsilon_w^2}{2} \quad (\text{Washout at LM site})$$

For the T_1 site, this condition becomes $\alpha_1 \leq \epsilon_w$, or

$$\frac{(\vec{R}_1 - \vec{R}) \cdot \vec{s}}{|\vec{R}_1 - \vec{R}|} \geq 1 - \frac{\epsilon_w^2}{2} \quad (\text{Washout at } T_1)$$

The corresponding conditions for glare are $\alpha \leq \epsilon_G$ and $\alpha_1 \leq \epsilon_G$, or

$$\frac{\vec{R} \cdot \vec{s}}{|\vec{R}|} \geq 1 - \frac{\epsilon_G^2}{2} \quad (\text{Glare at LM})$$

and

$$-\frac{(\vec{R}_1 - \vec{R}) \cdot \vec{s}}{|\vec{R}_1 - \vec{R}|} \geq 1 - \frac{\epsilon_G^2}{2} \quad (\text{Glare at } T_1)$$

where ϵ_G is a small angle in which glare is intolerable. Values of ϵ_w vary from about 2° to 10° and depend upon viewing angle, sun angle, and azimuth angle. Values of ϵ_G depend upon properties of the human eye, lunar surface, astronaut face-plate, and the above mentioned angles.

Once washout and glare zones have been defined and trajectories assigned to avoid them, it still remains to be determined whether contrast levels, as seen by the LFU pilot, will be sufficient. Contrast is defined as

$$C \triangleq \left(\frac{\partial \phi}{\partial \tau} \right)_{\alpha} \frac{\Delta \tau}{\phi},$$

where τ is the angle between the direction of viewing and the surface normal projected on the phase plane and ϕ is the photometric function. Hamza¹ selects a lower limit of 0.025 as being an acceptable value of this quantity. Figure 2 shows the region corresponding to values of α and τ for which $C > 0.025$ for the lunar surface. In order to insure sufficient relative contrast along LFU trajectories, values of α and τ must be computed along these paths and each point $\alpha(\tau)$ checked on Figure 2. These values are calculable from the general vector relations developed below.

Phase angles, α and α_1 , are easily obtainable from

$$\begin{aligned} \cos \alpha &= - \frac{\vec{R} \cdot \vec{s}}{|\vec{R}|} \\ \cos \alpha_1 &= \frac{(\vec{R}_1 - \vec{R}) \cdot \vec{s}}{|\vec{R}_1 - \vec{R}|} \end{aligned}$$

Angles τ and τ_1 are defined in Figure 3 and are somewhat more difficult to calculate. First, phase plane unit normal vectors are defined for each case

$$\vec{p} = \frac{\vec{s} \times \vec{R}}{|\vec{R}| \sin \alpha} \quad \text{and} \quad \vec{p}_1 = \frac{-\vec{s} \times (\vec{R}_1 - \vec{R})}{|\vec{R}_1 - \vec{R}| \sin \alpha_1}.$$

The lines of intersection between reflecting and phase planes are defined by the vectors $\vec{n} \times \vec{p}$ and $\vec{n} \times \vec{p}_1$, where \vec{n} is a unit

vector normal to the reflecting plane. Now the complement of τ is the angle between $\vec{n} \times \vec{p}$ and \vec{R} , giving the magnitude of this angle by

$$\sin|\tau| = \frac{|\vec{R} \cdot (\vec{n} \times \vec{p})|}{|\vec{R}| |\vec{n} \times \vec{p}|}$$

and similarly,

$$\sin|\tau_1| = \frac{|(\vec{R}_1 - \vec{R}) \cdot (\vec{n} \times \vec{p}_1)|}{|\vec{R}_1 - \vec{R}| |\vec{n} \times \vec{p}_1|}.$$

Another expression of $|\tau|$ is obtained by noting that the projection of the local vertical onto the phase plane is defined by $\vec{p} \times (\vec{n} \times \vec{p})$. Applying a familiar vector identity for the triple cross product gives

$$\vec{p} \times (\vec{n} \times \vec{p}) = \vec{n} - (\vec{p} \cdot \vec{n})\vec{p}.$$

Now $|\tau|$ is given by

$$\cos|\tau| = \frac{|\vec{R} \cdot [\vec{n} - (\vec{p} \cdot \vec{n})\vec{p}]|}{|\vec{R}| |\vec{n} - (\vec{p} \cdot \vec{n})\vec{p}|}.$$

A similar consideration for τ_1 gives

$$\cos|\tau_1| = \frac{|(\vec{R} - \vec{R}_1) \cdot [\vec{n} - (\vec{p}_1 \cdot \vec{n})\vec{p}_1]|}{|\vec{R} - \vec{R}_1| |\vec{n} - (\vec{p}_1 \cdot \vec{n})\vec{p}_1|}.$$

After a magnitude for τ or τ_1 has been calculated the sign of this quantity must be determined. The value of τ is positive only if

$$\alpha + |\tau| = \sigma$$

where

$$\cos\sigma = - \frac{\vec{s} \cdot \vec{p} \times (\vec{n} \times \vec{p})}{|\vec{p} \times (\vec{n} \times \vec{p})|}.$$

This condition corresponds to the situation in which the viewing line \vec{R} is between the sun line \vec{s} and projection of \vec{n} onto the phase plane. If this condition is not satisfied, then $\tau < 0$. For this work $|\tau| < 90^\circ$ and $0 \leq \alpha \leq 180^\circ$. Similar considerations give the necessary condition

$$\alpha_1 + |\tau_1| = \sigma_1$$

where

$$\cos \sigma_1 = - \frac{\vec{s} \cdot \vec{p}_1 \times (\vec{n} \times \vec{p}_1)}{|\vec{p}_1 \times (\vec{n} \times \vec{p}_1)|}$$

for positive τ_1 . If all points (α, τ) and (α_1, τ_1) for LFU trajectories fall above the curve of Figure 2, contrast at target sites relative to the pilot will be continuously acceptable.

Some further observations on pilot visibility are now in order. LM visibility from a returning LFU has not been considered as a separate area of investigation. However, photometric properties of man-made spacecraft will surely differ from those of the lunar surface. There may not be a contrast problem between the LM and its background. Nevertheless, this situation should be anticipated. If multi-stop sorties are planned, wash-out, glare, and contrast calculations should be made for trajectories from one stop to the next as well as for flights from LM and return-to-LM. Similar derivations to those presented above will give the appropriate formulae.

Landmarks must also be observable by the pilot for navigational and guidance purposes. If photography of the exploration area is available prior to the mission, landmarks will have been pre-selected and their visibility characteristics, relative to LFU sorties, computed. Target landing sites may be in shadow at exploration time. This situation must be anticipated and is easily checked by use of contour charts and a knowledge of the sun angle. Unless artificial light or reflected sunlight is available, shadowed areas cannot be visited for obvious reasons.

2.2 Trajectory Profile and Sortie Sequence

Lunar Flying Unit trajectory configurations are of critical importance to efficient exploration techniques. An ideal flight between two given points would:

1. require a minimum of propellants,
2. consume a small amount of time,
3. provide sufficient opportunity for the pilot to make navigational and scientific observations,
4. have trajectory characteristics which permit the pilot to control and maneuver the vehicle without the aid of automatic equipment,
5. provide good approach-to-target site characteristics,
6. insure sufficient lighting and contrast along trajectory with respect to observation points.

The optimum trajectory for minimum propellant consumption is ballistic. To get a theoretical lower limit on propellant requirements a flight from point A to point B under uniform gravity conditions is briefly considered. Figure 4 illustrates this situation. Given the positions of end points A and B, the launch (or take-off) angle γ and minimum initial velocity to reach B are

$$\gamma = \frac{\pi}{4} + \frac{\zeta}{2}$$

$$V_A = \left[\frac{gR}{\cos\zeta - \tan\zeta(1-\sin\zeta)} \right]^{1/2}$$

and the landing angle and final velocity at B are

$$\gamma' = \frac{\pi}{4} - \frac{\zeta}{2}$$

$$V_B = \left[\frac{gR}{\cos\zeta + \tan\zeta(1+\sin\zeta)} \right]^{1/2}$$

where

$$\zeta = \tan^{-1} \left(\frac{h}{R} \right).$$

These relationships yield velocities corresponding to minimum propellant consumption for a ballistic flight. However, these considerations are only of academic interest to lunar astronauts. Initial and final accelerations are large, velocity and altitude values are high, and engines remain off during most of the flight. This last characteristic may be unacceptable.

Each sortie is time-limited. In order to maximize exploration time at each site, fast LFU flights are required. However, the pilot must be traveling at a speed which allows him to observe terrain and make appropriate decisions. A speed and altitude profile should be considered on the basis of pilot performance requirements. Furthermore, pilot control functions can be reduced by employing trajectories in which landing site accuracy is not sensitive to initial flight velocity components, e.g., flat-top profiles. It is also desirable to avoid situations which require large changes in thrust level in order to maintain high engine efficiency. Each trajectory should be oriented such that the final approach to a site will provide visibility and sufficient contrast of the area.

Much of the lunar surface seems to be covered with at least a thin layer of fine grain material. Rocket exhaust will probably cause fine grain material to lift off the surface just as the LFU lands and takes off. Possibilities of reducing this disturbance through trajectory modifications seem very limited. One solution might be the adaptation of automatic shut-off devices which are activated by rods extending below the vehicle. In addition to obscuring site visibility, this fine material may be blown into the rocket nozzle after shut-down as particles are carried by captured gases which are released from the surface directly below the engines. Additional discussion of this problem is presented in section 2.4.

Many trajectory profiles have been considered for various reasons. Powers³ analyzes ballistic, semi-ballistic, and flat trajectories. A semi-ballistic flight is one in which finite thrust intervals are used. During the parabolic phase engines thrust downward at a low level, resulting in an effective reduction of the already low lunar gravity. An even less optimum use of propellants occurs with flat trajectories. Here a constant altitude is maintained between end points. Since the proposed LFU designs are of minimum weight, their complexity must also be held to a minimum. The pilot will be required to simultaneously

perform throttling, attitude, and directional control functions while navigating and observing landmarks. Therefore, trajectory profiles must be simple and non-optimum from a fuel-economy point of view. Semi-flat type trajectories appear to be a more logical choice after considering the capabilities of the pilot, Penzo⁴ has studied this type of trajectory in detail. A typical flight begins with a short vertical rise. The pilot then pitches the vehicle forward. Thrust level and attitude are held until a desirable horizontal velocity has been reached, then the pitch is corrected to vertical and thrust is reduced to less than the weight. A semi-flat cruise phase then commences. Descent and landing phases are essentially symmetric with ascent phases.

Meyer⁵ presents several trajectories based on operational requirements. Figure 5 illustrates three profiles which seem to incorporate some of the desired features. Configuration (a) is a flat-top trajectory with the various phases of flight marked. This profile is most useful when flying between two points at approximately equal elevation and making navigational and scientific observations along the way. Configuration (b) reduces the amount of deep throttling required by reducing the final approach altitude. This type of trajectory is most useful when the touchdown site is visible from an appreciable distance, e.g., return trip to LM, and when point B is at a lower elevation than A. Configuration (c) is useful when point B is above point A in elevation. During the final approach of any of these profiles, the pilot is pitched back and looking upward. In order to see the landing point he should perform a 180° yaw (pilot roll) as he pitches up. Upon landing he will then be facing his approach direction. Specific performance figures for each of these trajectory shapes depend upon such factors as relative positions of A and B, pilot performance capabilities, engine performance, and sortie objectives.

2.3 Line-of-Sight Requirements

Special consideration must be given to the spatial relationship between the LM site and LFU position at any instant of time. Communications capabilities of an astronaut on this LFU design are limited to line-of-sight transmissions, so that rescue operations can start if and when needed. Therefore, any point in a trajectory which obstructs the line between the LM and LFU must be avoided unless a relay unit can be positioned to provide continuous communications. If an astronaut is out of line-of-sight with the LM while at an exploration site, he must have a reference by which to steer the LFU during take-off and until the LM is sighted.

2.4 Lunar Surface Interaction Hazards

It has been established that much of the lunar surface is covered with at least a thin layer of fine grained material. Impingement of LFU rocket exhaust onto the surface may cause several effects detrimental to exploration operations. Particles will obscure vision and possibly strike the vehicle and any equipment in the vicinity. References 6 and 7 present studies of the hazards and mechanics of this impingement problem. Three types of erosion may occur. Viscous erosion is caused by shearing forces resulting from radial gas flow along the surface. Explosive cratering is caused by normal forces on surface particles resulting from gas static pressure. Diffused gas eruption occurs after thrust termination and is caused by an increased subsurface pressure resulting from gas pressure during thrusting. Thus, unbalanced pressure forces displace the soil upward and a rupture of the surface occurs. Particles could be blown into LFU rocket nozzles and result in later re-start failures of these engines. One possible prevention measure to insure reliability is to terminate thrust at a slow shutdown rate such that pressure in the nozzles would be large enough to blow soil particles out before they settle.

A thrust impingement model will be of importance for planning purposes. The rocket exhaust is hypersonic in the lunar atmosphere. Therefore, it is undisturbed by the surface below until it reaches a shock wave, parallel to and just above the dust layer. Once this shock is passed, the gas flows in radial directions along the surface. A crater is initially formed in the shape of an annulus with an undisturbed center section due to flow stagnation at that location. Finally, this crater takes the form shown in Figure 6. Downstream of the shock wave, flow is subsonic, but becomes supersonic as the radial distance increases. The shearing force of radial gas flow produces particle motion. Erosion takes place, and with it, the surface profile and gas flow field change. The result is an expanding crater beneath the LFU rockets.

3.0 MISSION ASPECTS - EXPLORATION OF HYGINUS

In an effort to demonstrate some of the operational problems of using an LFU, the following example mission is considered. Two astronauts arrive in an Extended LM (ELM) at a plateau above Hyginus Crater and Rille. Touchdown point is at 8°3'N, 6°12'E. This vehicle will carry two LFU's of the assumed

configuration. Objectives of this mission are to visit and explore areas of scientific interest in the region around this rille and crater system. Figure 7 illustrates the ELM site and locations to be explored. The three primary LFU landing points are shown as A ($7^{\circ}45'N$, $6^{\circ}14'E$), B ($7^{\circ}57'N$, $6^{\circ}2'E$) and C ($7^{\circ}51'N$, $5^{\circ}56'E$). At time of touchdown, the sun angle is assumed to be 6° . This is to be a three earth-day exploration of the region. However, the first sortie cannot be performed until approximately 12 hours after arrival because of house-keeping functions, a sleep period, and equipment unloading operations. At this point the sun angle is about 12° above the morning terminator. Since ELM residual propellants will allow only a limited number of LFU refuelings, it is desirable to perform long distance sorties first. While these are being executed, filled reserve tanks will be in place on the rescue vehicle, thus enabling this LFU to fly to a distant disabled LFU without payload, drop empty reserve tanks and load the other astronaut on, and return to the ELM.

Site C is 10 km away from the ELM and at about the same elevation. Therefore, a direct flight can be made without intermediate stops. It is easily seen that the phase angle relative to site C is always significantly different from 0 and 180° for the assumed lighting conditions and flight direction shown in Figure 7. Therefore, washout and glare will not be encountered along the flight paths. The level of contrast at point C as seen by the pilot is not so easily determined, and the required calculations are lengthy. However, this can be avoided by making the following observations. Since α is well above zero here, Figure 2 implies that for almost any positive value of τ , contrast is acceptable. The value of τ is positive when the viewing line is between the sun line and projection of the local normal onto the phase plane. This happens when viewing angle is significantly greater than sun angle for acute azimuth angles. In other words, if the final approach to site C is steep, then τ will be positive and contrast is acceptable. As the LFU approaches touchdown, rocket exhaust impinges on the lunar surface, and interaction hazards mentioned previously are manifested. Visibility may be somewhat obscured, particles may collect on the vehicle and any equipment in the vicinity may receive a coating of soil material. Equipment and instrument packages may have to be placed well away from take-off, approach, and touchdown areas. On the return flight from site C to ELM, the pilot should make reconnaissance observations required for a later sortie to site B. Since this location is about 200 meters below the elevation of the ELM and on the floor of a rille, line-of-sight requirements cannot be

satisfied unless a relay station is placed at point B-LM. This point can be observed by the pilot upon returning from C if he looks to his left. Before passing point B-LM, values of phase angle are in the range corresponding to no washout or glare of this point with respect to the LFU trajectory. Since α has large values, the contrast level should be acceptable, at least until point B-LM is passed. After that the pilot will not be able to see this area, because it will be behind him and possibly in a washout area. The trip to site C and back, including site exploration, consumes about 3 hours. An equal amount of time is assumed necessary before the second sortie can start. The sun angle at the beginning of this trip is 15° . Logically, the next site to visit is A. However, this point is on the bottom of a crater and about 1,000 meters below the ELM landing site. Line-of-sight requirements again cannot be satisfied without the emplacement of a relay at point A-LM. If the maximum propellant loading of 300 lbs and a payload of 100 lbs are assumed, this vehicle cannot make a stop at A-LM on the way to site A.⁵ Therefore, a separate trip to A-LM is necessary in order to explore site A. Finally, the other astronaut leaves for location A after the first one refuels and gets ready for rescue operations, if required. The sun angle is then 16° and the azimuth angle is near 90° for this round trip. It is apparent that τ has values around -45° for both legs of this sortie. Since α is larger than 30° , these values of τ still permit an acceptable contrast (see Figure 2). Flight trajectories should take advantage of the elevation difference between A and LM. A profile similar to Figure 5(b) might be appropriate for the outbound leg. This would conserve fuel and provide some of the extra energy required to climb out of the crater. Figure 5(c) might be a good choice of profile for the return leg.

The next sortie is made after a sleep period, when the sun angle is about 24° . This will be the last LFU trip and is to site B (5.8 km away from ELM). Phase angle α will be large enough for good visibility and contrast, except possibly in final approach phases. An intermediate stop at point B-LM is required to place a relay. The trajectory from ELM to B-LM can be the flat top type and from B-LM to B a simple descending flight is suggested. The return flight might employ a steep ascent (shallow descent profile, Figure 5(b)). The

astronaut may experience glare when looking up from B to B-LM, but this is not important if the initial phase of the return flight is steep enough to avoid the rille wall.

A minimum of shadowing will be encountered with this sortie sequence. Figure 7 indicates a large geometric shadow near site B. However, this location will be visited when the sun is considerably higher than the 18° angle of this photograph.

4.0 SIMULATION REQUIREMENTS

A comprehensive simulation program is suggested for the LFU before its first operational use. The primary purposes of this are to train astronauts and determine their limitations under varying situations, define subtle problems otherwise unforeseen, and provide inputs to LFU designers to insure a compatible vehicle for proposed applications.

Several types of simulations are required. Identification of landmarks at LFU speeds is a talent acquired through training and practice, and actual LM landing experience. If the Moon has no magnetic field, navigation of this simple vehicle must be performed by pilotage, i.e., identification of landmarks. Since lunar formations will appear different for varying lighting and contrast conditions, identification training should incorporate a simulation of this phenomenon. Realistic missions can be performed on Earth by using jet powered flying units. These will permit real-time simulations and training sequences. Exploration situations can be generated and operational procedures developed.

5.0 SUMMARY

Some significant problems related to Lunar Flying Unit operation have been exposed and discussed. Lighting and visibility requirements with respect to LFU pilots are very important, because navigation and reconnaissance must be done with inputs to human eyes only. Once a mission site and sorties are selected, a computer program can yield visibility and contrast conditions along any given LFU path. Complete washout, glare, and low contrast zones can be plotted with the resulting figures. Shapes of LFU paths are also important because they will complement the pilot's abilities and mission objectives if properly selected. One computer program can handle several aspects of a mission: visibility and lighting, fuel requirements for given trajectory profiles, and line-of-sight violations. Surface interaction hazards should be investigated further and optimum methods of minimizing these effects developed. Simulation programs should be used extensively for pilot training and LFU development.

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Attachments
References
Figures 1 - 7

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Attachments
References
Figures 1 - 7

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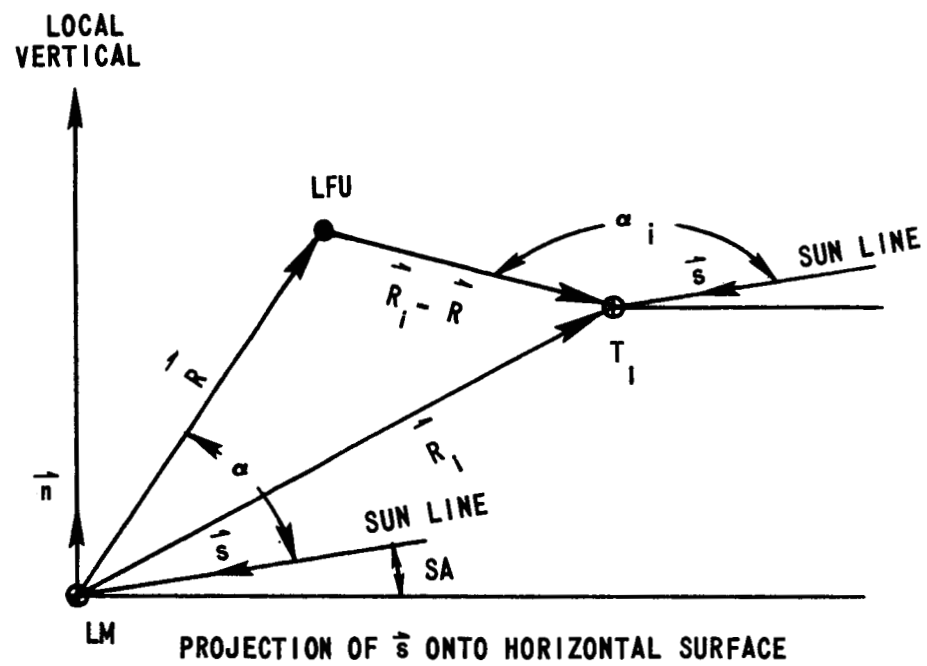


FIGURE 1 - LFU VISIBILITY NOMENCLATURE

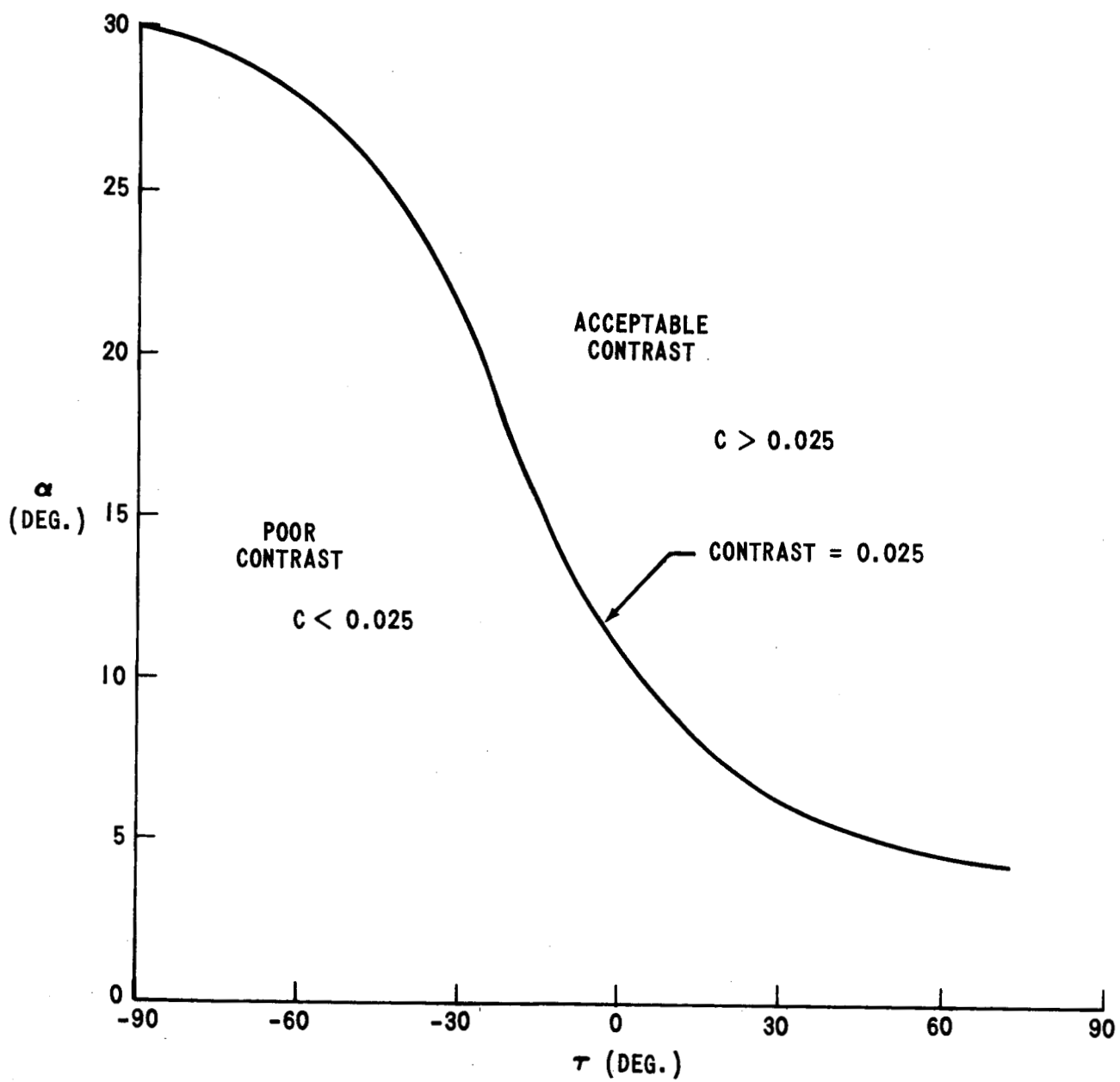


FIGURE 2 - DEFINITION OF ACCEPTABLE CONTRAST RANGE

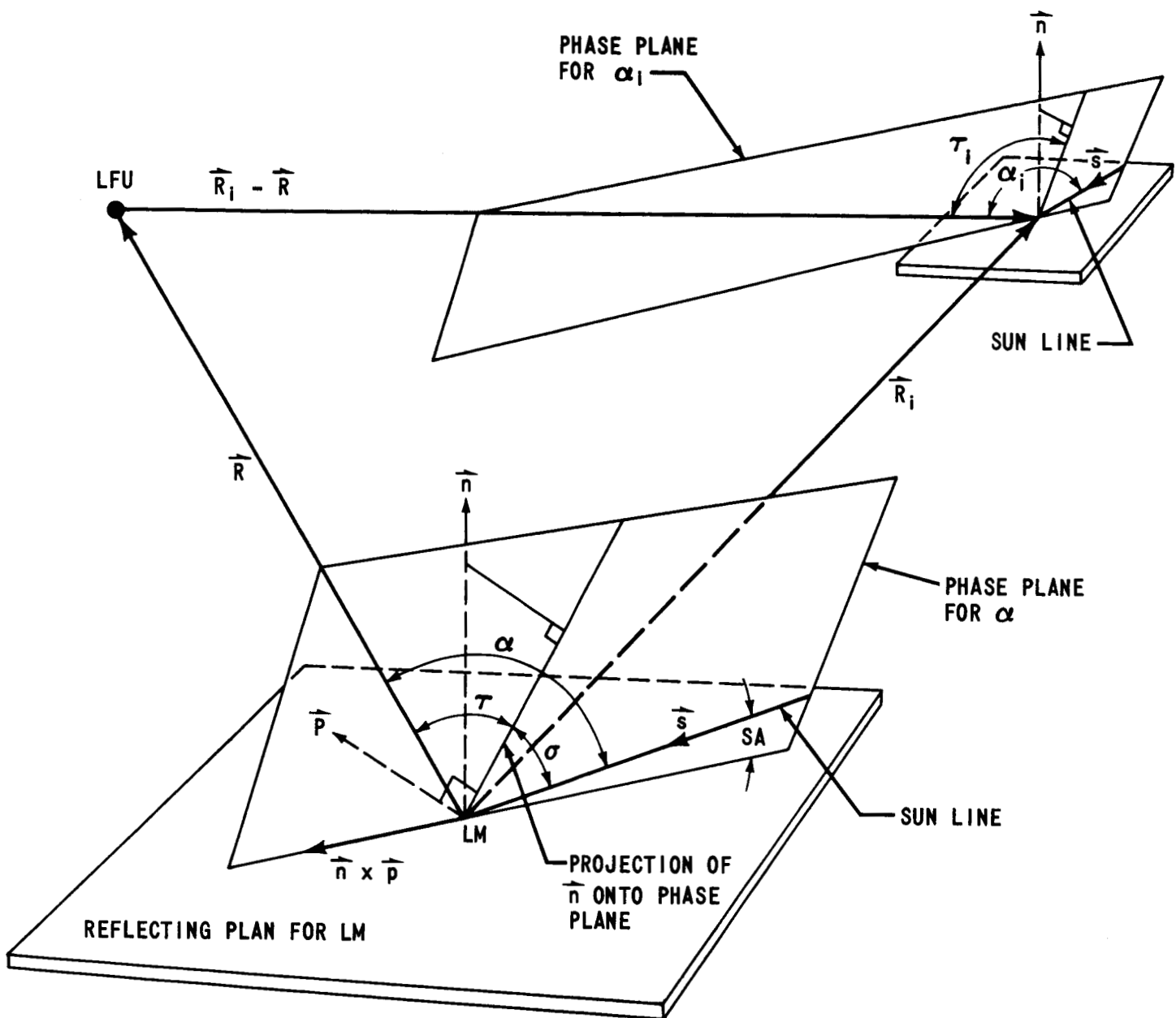


FIGURE 3 - NOMENCLATURE FOR DETERMINATION OF CONTRAST

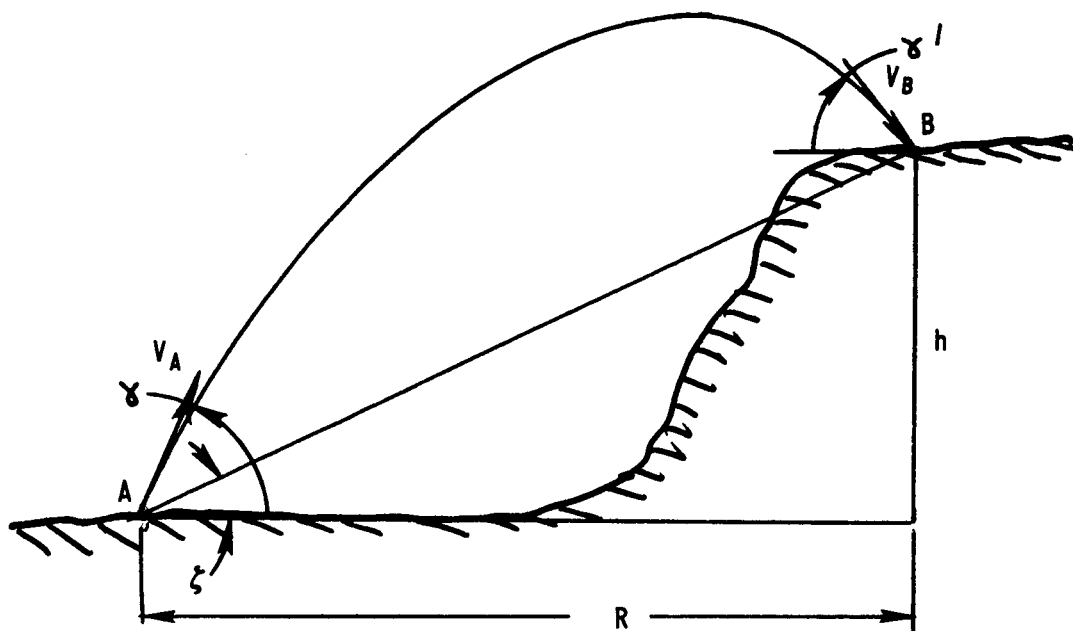
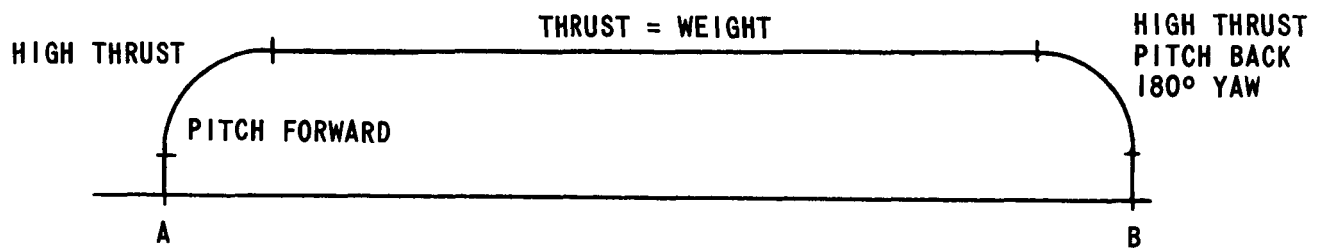
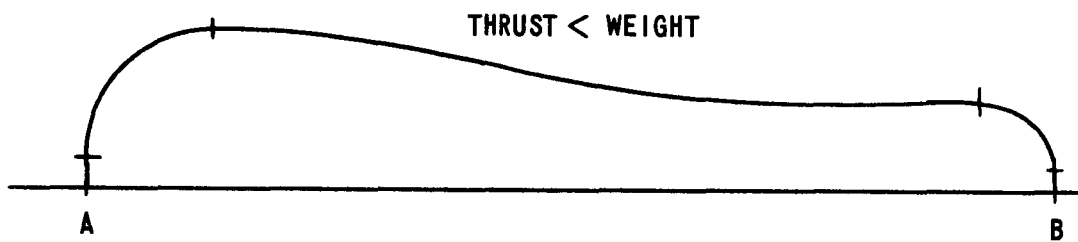


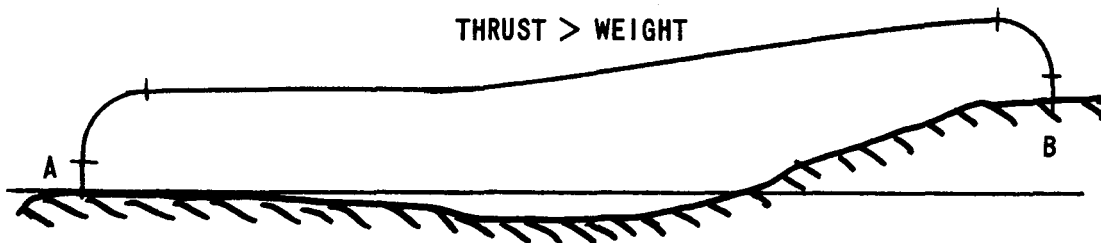
FIGURE 4 - NOMENCLATURE FOR BALLISTIC TRAJECTORY



(a) FLAT - TOP



(b) SHALLOW DESCENT



(c) SHALLOW ASCENT

FIGURE 5 - LFU TRAJECTORY PROFILES

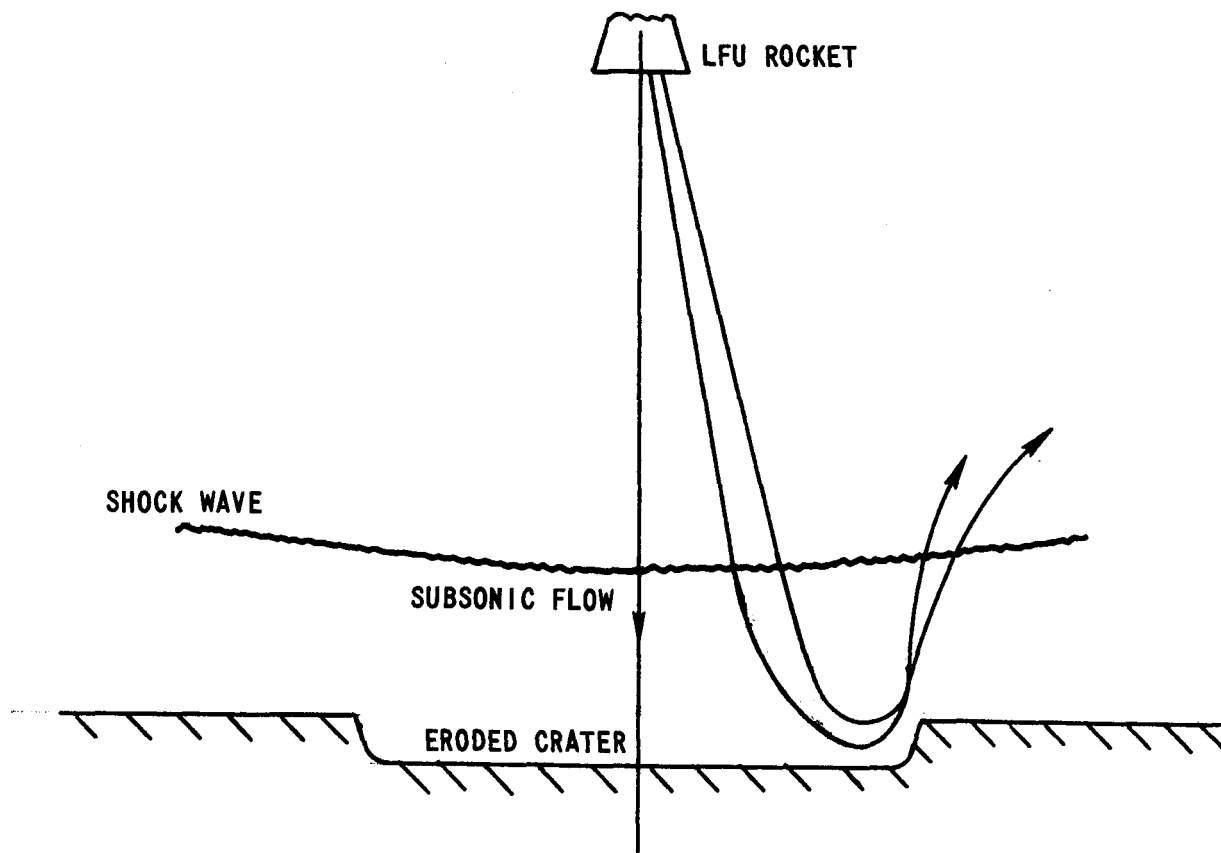


FIGURE 6 - ROCKET IMPINGEMENT MODEL

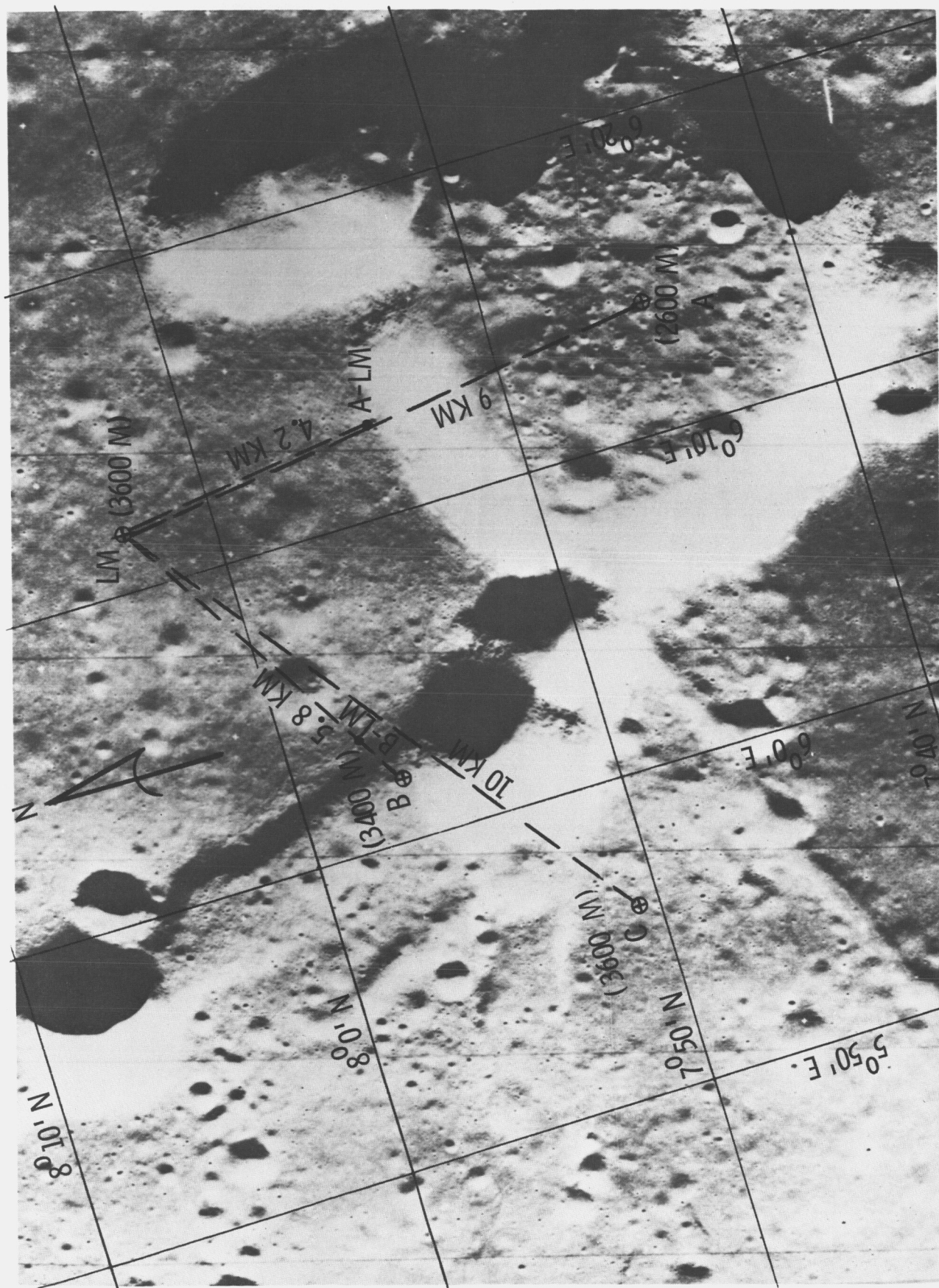


FIGURE 7 - EXPLORATION OF HYGINUS